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ABSTRACT

The failure of colleges and universities to ensure that all undergraduates become scientifically and technologically educated was addressed at the 1982 Wingspread Conference. Representatives of education, business, government, and other professions considered the place of science and technology education within liberal education and formulated a set of actions and strategies that individual colleges and universities can implement. The conference recommendations are grouped around four main issues: leadership; institutional commitment and support; standards both for admission to and graduation from college; and improvement of science courses and introduction of technology courses for nonmajors. The following two conference papers are also included: "Sputnik, Halley's Comet, and Science Education" (F. James Rutherford); and "The Place of Science and Technology in the Liberal Arts Curriculum" (David S. Saxon). The first paper introduces the problem by noting that students are avoiding science and mathematics courses/majors, the science/mathematics curricula are obsolete, and there is a cutback in support of science teaching. The second paper includes examples that illustrate our inability to distinguish between sense and nonsense in matters concerning science and technology. (SW)

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Science and Technology Education for Civic and Professional Life: The Undergraduate Years

A Report of the Wingspread Conference

Wingspread Conference Center
Racine, Wisconsin
June 1-3, 1982

HE 016 275

Sponsored by

Association of American Colleges
and
American Association for the Advancement of Science

Support for the conference was shared by the Johnson Foundation, which provided the Wingspread Conference Center, Racine, Wisconsin, as the meeting site, and by the Exxon Education Foundation and the Alfred P. Sloan Foundation, which provided funds to cover other expenses.

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Contents

Preface v

Sputnik, Halley's Comet, and Science Education
F. James Rutherford 1

The Place of Science and Technology in the Liberal Arts Curriculum
David S. Saxon 5

Conference Recommendations 15

Wingspread Conference Planning Committee and Participants 27

Preface

There are growing concerns among scientists, educators, and the general public over the average citizen's lack of scientific knowledge and the failure of colleges and universities to ensure that all undergraduates become scientifically and technologically educated. The Association of American Colleges (AAC) and the American Association for the Advancement of Science (AAAS) jointly sponsored a conference June 1–3, 1982, at the Wingspread Conference Center in Racine, Wisconsin to address these concerns.

The Wingspread Conference brought together more than 60 persons concerned about the place of science and technology education within liberal education. One fundamental assumption they held in common can be characterized by a statement of David Saxon, the physicist-president of the University of California, who said in his keynote address: "If the ability to distinguish sense from nonsense is an indispensable aspect of liberal education . . . , then in a technological society, science is an indispensable part of the liberal arts curriculum."

Although the conferees recognized that serious weaknesses exist in elementary and high school preparation in science and technology, this conference focused only on the undergraduate years. The participants held as a working premise that improvement of college education in science and technology would not only be one of the primary ways to remedy the national problem, but would also help overcome the deficiencies of elementary and secondary school preparation by setting goals for them and by elevating the standards of training for primary and secondary school teachers.

The conference began with introductory remarks by F. James Rutherford, chief education officer for the AAAS, and a keynote address by David S. Saxon, president of the University of California system. Background reading for the conference was the National Research Council Report, *Science for the Nonspecialist: The College Years* (National Academy Press, 1982). The information in the NRC report and the charges to the conference by the opening

speakers set the tone for the discussions that followed. The speeches by Rutherford and Saxon comprise the first section of this report.

To facilitate discussion, the conference was divided into five working groups. They dealt with: 1) the appropriate curricula in science and technology in undergraduate education; 2) the relationships between science and technology and other fields in the total educational program; 3) the techniques for teaching and learning science and technology; 4) the need for institutional commitment and resources; and 5) the methods to promote faculty initiatives and peer support for improvement. The working groups outlined a series of goals and recommendations, which were then discussed by the entire conference.

The AAC and AAAS received financial support for the conference from the Exxon Education Foundation and the Alfred P. Sloan Foundation. In addition, the Johnson Foundation hosted the conference at its facilities at Wingspread. The sponsors and participants in the conference wish to thank those foundations and their staffs for their generous support in making the meeting a success.

Finally, this was the fourth in a series of Wingspread Conferences sponsored by the Association of American Colleges on current problems in undergraduate education. Previous conferences have examined the neglect of foreign languages and international studies in a college education, the crisis in the humanities, and the challenge of new feminist scholarship to instruction in the liberal arts. Reports on these earlier conferences have been produced and distributed by the Association of American Colleges.

Sputnik, Halley's Comet, and Science Education

F. James Rutherford

Things seem to come in cycles—sunspot activity, locusts, hula hoops, comets, educational reform. Halley's Comet, last seen in 1910, is due back and should be visible this October through powerful telescopes. October is the anniversary month of Sputnik as well.

It was just twenty-five years ago on October 4th that we were jolted by the news that the Soviet Union had successfully launched an earth satellite. In an instant we became aware of what some educational leaders had been claiming for several years, namely that science education in the United States was weak and inadequate for the times. Now, a quarter century later, we are once again hearing that our deficiencies in science education have put us at risk.

What are we to make of this? Are our troubles in science education merely cyclical, the swing of the pendulum? In seeking an answer let us reflect briefly on both Halley's Comet and Sputnik.

Comets are fabled creatures. The one bearing Edmund Halley's name was, in the scientific way of things, discovered by him, and then again, it was not. Its first documented sighting was by the Chinese in 239 B.C. Every reappearance since then has been found in both visual representations and in written records. Giotto must have seen this comet in 1301 for he depicts it as the Star of Bethlehem in his fresco "Adoration of the Magi." It was represented again in the famous Bayeux Tapestry commissioned to commemorate William the Conqueror's victory in the Battle of Hastings in 1066 and, nearer at hand, Mark Twain said, "I came in with Halley's Comet, and I'll go out with it." And he did. Twain was born in 1835 and died in 1910.

Edmund Halley (1656–1742) examined the historical records available to him and was able to calculate accurately the period of this comet. It is because of his work and what followed that we

now know that we will see this most famous of all comets in its full glory in February 1986, and we know just when it will return for all future generations.

But let's turn things around for a moment by imagining that the comet could observe us. Would it recognize today's world as being the same one it "visited" in 1910 (let alone in 1835 or 1758)? Hardly. Consider: the world's population will have jumped from about one-and-one-half billion to five billion. The things people will seem to be using for transportation, communication, research, construction, recreation, anything, mostly did not exist in 1910—jet aircraft and gas guzzlers, super highways and intercontinental missiles; four generations of computers; robots assembling robots; earth satellites and particle accelerators; T.V. and L.P.; the bomb. And the work people do—having changed in the interval from farming to manufacturing to service—and the issues that confront them —nuclear annihilation and the population explosion being the two frightening extremes that encompass others such as resource depletion and environmental degradation—are radically different from what they were 75 years ago.

If we go back still another Halley cycle, comparing the world of 1910 to the world of 1835, once again the comet would report large differences, but they would be less dramatic. And 1760 still less, and so on back to the 19 trips to 239 B.C., or further. Not only is the world the comet returns to each trip different from the way it was the time before, but the magnitude of the difference is greater, probably exponentially so.

This kind of comparison tells us two things about the world of the future. It tells us that we cannot now accurately describe the world as it will be when Halley's Comet next returns in 2062. Of course it will be different from today's world; but in precisely what ways we cannot predict any more than the world of 1985 could have been foretold in 1910. But this we do know: the changes that will be brought about in our culture and in our way of life, will have more to do with the utilization of science and technology than with anything else. If our civilization is here next time around, it will be a world that more than ever before, more than even now, will be based upon science and technology—for better or worse. If human civilization is not here, a real possibility, it will be because we failed to come to terms with ourselves as the generators of knowledge and the users of technologies.

Translated into educational terms this means that we must now

learn how to prepare the graduates of our schools and colleges for a world of science and technology. The evidence tells us that we are not doing so. We see test scores falling, students avoiding science and mathematics courses, fewer students electing science majors, a collapse of the teacher preparation enterprise in science and mathematics, the obsolescence of the science and mathematics curricula, and a cutback in support of science teaching. Where, one might plaintively ask, is *our* Sputnik, to wake us up, to get us going?

One answer is that we already have it, and it is called Sony or Nissan or Mitsubishi. The threat this time may not have appeared so suddenly, but it is no less expected and is much more fundamental. It has to do with the increasing determination of Japan, the Germanies, the Soviet Union, and many other nations to seize the technological initiative, just at the moment when we are reducing our commitment to the very science and technology that is the basis for a strong economy and for world leadership.

Another answer is that while Sputnik was the spark that led to a national effort to improve science education, it was not an unmixed blessing then, and it is not likely to work today anyway. Two crucial factors are missing: leadership and consensus. In contrast to the national leadership that existed following Sputnik, including a mandate from President Eisenhower, the federal government is now in retreat educationally, if not in disarray. The President of the United States has made it clear that whatever the problem is, it is a matter to be addressed by the individual states and local school districts, with perhaps some help from the private sector. The U.S. Department of Education is barely able to survive let alone foster anything as creative as the massive federal program in 1958 to upgrade science, mathematics, and foreign language training, and the education programs at the National Science Foundation have been essentially eliminated. There is no single national voice, no real call to action from the top.

Furthermore, even though we seem gradually to be registering concern about our situation, we have been unable to agree on what to do about it. We accuse our business people of not being enterprising enough, our government of putting too many shackles and restraints on our people and institutions; we claim that our workers are not good enough or do not work hard enough, we point to the unfair competition from former friends abroad, and we seem to have lost confidence in public education. In short, unlike before, there is no broad consensus that science and mathematics educa-

tion *for all* is fundamental and essential. We lack a popular mandate.

But even if we could have "our own" Sputnik to motivate us, I doubt that we would want it. Think what happened last time. Almost from the outset our response to Sputnik was as though we were in a high-stakes sporting contest. The U.S.A. and the U.S.S.R. were the only competitors in "The Space Race." Our task, our challenge, was to become dominant in space—which we soon came to believe meant getting a man to the moon first. To win we would have to invest heavily in space technology, and also accelerate the production of first-rate scientists and engineers, which is to say train more young people for technical careers.

That was where we went awry educationally. By casting our response to Sputnik in terms of a particular contest rather than of longer-range national goals, we made it probable that the public would lose interest in science education once the contest (as perceived) had been won. What is worse, by concentrating on the production of scientific and engineering manpower we were diverted from the effort already underway to strengthen the science education of all our students. What the country needed then and what it needs even more now is a society made up of high school and college graduates who can come to terms with the scientific and technological realities that confront them daily—as citizens, as workers, as human beings. Scientifically and technologically literate citizens form the necessary base upon which to build and sustain a democratic society in a technological world, and that is what we need to work toward.

The lesson of Sputnik is its failure to catalyze a broad-gauged and lasting reform movement in science and technology education. Every student needs a good general education, and in these times such an education must pay substantial attention to science and mathematics and their applications. In this the undergraduate institutions have a heavy responsibility, for it is through them that the professionals and the business and political leaders of the 1990s and beyond will pass. Graduates of the next quarter century will determine whether when Halley's Comet returns in 2062 there will be a world of human beings at all, and, if so, what kind of world it will be.

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The Place of Science and Technology in the Liberal Arts Curriculum

David S. Saxon

I am particularly delighted at the opportunity to join you this evening, for I understand the deep importance of your assignment. Also its difficulty. You have been asked to address the question of the pervasive lack of knowledge and understanding of science and technology amongst those most educated of Americans, our college graduates. And, at a more fundamental level, to address, at least with respect to science and technology, the question of what constitutes a genuinely liberal education in this technological society and age. But not merely to address these questions; to propose as well a course of action based on your answers.

A significant first step has already been taken; we agree that our technological illiteracy—as it has been called—is a major problem, even a national scandal. Your presence here testifies to the fact that there is a consensus about the seriousness of the problem, so we start out that much ahead.

Teaching science to liberal arts students is something I have always taken seriously, from the moment I began teaching physics more than thirty-five years ago. And I know just how hard it is, having tried to do it myself on many occasions over those three and a half decades, using a variety of approaches, and having been responsible for a failed textbook on the subject. Be assured; I am under no illusions. You will get no simple prescriptions from me. Nor will you get a prescription about just what it is that constitutes a liberal education.

What you will get is, first, an attempt to define exactly what the problem is, to define precisely what I think we mean when we talk about our lack of knowledge and understanding of science and technology. Second, an attempt to understand what the roots of that problem are. Third, a brief attempt to define the proper place of science and technology in the liberal arts curriculum.

I have spoken on—and struggled with—certain aspects of this topic before. I have spoken to my colleagues in the sciences about their share of the responsibility—and perhaps blame—for the extent of our scientific illiteracy and suggested steps they ought to take in their own intelligent self-interest to address that problem. A few years ago, in an address to the Phi Beta Kappa Society, I emphasized the corresponding responsibility of students and faculty in the humanities. I have also talked to a group of broadcasters about the way the news media add to the problem and what they need to do to play a proper and responsible role. As I did on those occasions—and as I've already promised—I will begin by defining the problem.

Simply stated, the problem is that we are quite unable, as a society, to distinguish between sense and nonsense when it comes to science. The problem is that educated, intelligent, inquisitive people are unable consistently to bring informed judgment to bear on questions connected in almost any way to science and technology, questions often vital to the welfare of each of us and indeed to the future of the world. Instead, the great majority of broadly educated people must rely on, and are at the mercy of, the testimony and assertions of others. Furthermore, the degree of reliance required demands a faith that borders on the credulous. One of the distinguishing characteristics of a liberal education is that it should provide just that critical sense which makes it possible to winnow out the meretricious from the meritorious. Yet many liberally educated people are unable to do anything of the sort when it comes to science and technology.

That this is indeed the case is not an original observation, or even a new one. Over fifty years ago George Bernard Shaw summed it up when he said, "We believe [the earth] to be round not because as many as one percent of us could give the physical reasons for so quaint a belief, but because modern science has convinced us that nothing that is obvious is true, and that everything that is magical, improbable, extraordinary, gigantic, microscopic, heartless, or outrageous is scientific." And this was more than half a century ago—before we had even imagined nuclear energy, neutrons, (let alone neutron bombs), quantum field theory, lasers, quasars, black holes, quarks, DNA, or genetic engineering.

"Nothing that is obvious is true . . . ." We are expected and accustomed to accept what we are told without experiencing it or understanding it for ourselves. No wonder we are so often unable

to tell the credible from the incredible, science from pseudo-science, sense from nonsense.

That this observation is neither new nor original is a reflection of how old—and how tough—the problem is. Why, then, has a consensus developed at this juncture that something must be done, and done urgently? Because our society is becoming increasingly and irreversibly technological, and because scientific investigation is increasingly and irreversibly concerned with almost unimaginable extremes of space and time, which removes it ever further from the realm of our daily experience. Unless we acquire understanding, we will remain where we are right now, at the mercy of experts—or, worse, of charlatans posing as experts.

Let me describe one aspect of what I mean by citing some examples. Here are three statements about microwaves, all from published documents, all items I came across not so long ago:

- From a report on the possibility of using microwaves as an energy source:

  The purpose of this report is to call attention to the possible great social benefit that would be derived from the use of microwave radiant energy to provide directly the warmth needed by human beings and other living creatures. A strong motivation for this proposal at this time, in spite of growing concern about possible dangers, is the view that such use could contribute importantly toward alleviating the world energy crisis.

- From a book on the impact of microwaves on health:

  Microwave radiation can blind you, alter your behavior, cause genetic damage, even kill you. The risks have been hidden from you by the Pentagon, the State Department, and the electronics industry.

- From a story that appeared in the press:

  It was proposed that the United States launch space stations that would orbit the earth, collect solar energy, and beam it back to the earth, using microwaves. Such a project, its proponents argued, would largely solve the world's energy problems.

These accounts are similar to dozens of proposals or assertions that we read about daily in newspapers and magazines and hear about on television and radio. You have all heard it said that the world's supply of coal is more than adequate to take care of our energy needs for centuries; but you have also seen reports that use of coal will sooner or later—but irreversibly—cause the sun to heat up the atmosphere and by so doing to melt the polar ice caps and inun-

date the earth. (Incidentally, there are other predictions that it will do just the opposite and cause a new ice age.) And the fierce debate over nuclear power rages more fiercely—and less rationally—than ever. Whom do you believe, and how are you to know?

I bring up these questions to illustrate the problems we face because we live in an increasingly technological society, one in which, to use Shaw's words, we are convinced that "Nothing that is obvious is true, and that everything that is . . . heartless . . . is scientific." Will microwaves kill you or save you from freezing to death some day? What is the feasibility of collecting solar energy in space and beaming it back to earth? Most people don't know. Worse, they don't even know how to go about finding a reasonable answer.

That illustrates the first aspect of the problem. Let me now describe the second, related but different. It has to do with the realm of personal belief, and with the largely anecdotal evidence on which people build many of those beliefs. Why do so many educated, intelligent, inquisitive people believe in such things as UFOs, psychics, ESP, precognition, psychokinesis, astrology, biorhythms, and pyramid power? On reflection, I suppose the fact that they do isn't all that surprising. After all, many of our own faculty have no difficulty believing in one or more of them. It can be argued, of course, that matters of personal belief—especially when they revolve around such apparently harmless notions as, say, the belief in visits from ancient astronauts—can be dismissed as having significance only to the individual involved. I don't believe that. For one thing, that so many people find it easy to believe in pyramid power, in the supernatural hazards of the Bermuda Triangle, in the reality of precognition, reflects a grave misperception of the laws that govern our universe—and a grave failure of our educational system. For another, it is clear that personal beliefs and our state of mind can have a profound and sometimes dramatic effect on individual performance and well-being. There are many instances of this, among them the tendency of beginning medical students to think they have developed the symptoms of each illness they study, one by one.

It is also clear that personal beliefs can influence the decisions we make about our own well-being, decisions that can be disastrously wrong. The Beverly Hills Diet is only the most recent of a long string of fad diets characterized by an amazing ability to inspire faith and an unfortunate tendency to completely ignore nutritional principles. Or take the healing properties of copper bracelets for

people who suffer from arthritis. Or the controversy over Laetrile. Some of the many hundreds of popular beliefs about health are harmless, others dangerous. Just about all of them are based on wishful thinking or on undifferentiated and unevaluated anecdotal evidence of one kind or another—sometimes firsthand, sometimes second, but evidence that is more often than not negated by anecdotes on the other side of the question, if one only looked.

This brings us to a contradiction. On the one hand I've said that when it comes to science, most people do not have any experience of their own to rely on but must instead rely on the testimony of experts. But I've also asserted that even in the realm of their daily lives, personal experience is a far from infallible guide. So the question is not just whom do you believe but what do you believe—and on what basis?

This contradiction exists for two reasons. First, modern science deals with the physical world at a level so abstract and so remote from everyday experience that there is no way such experience could act as a guide in distinguishing sense from nonsense. Science expresses itself in the language of abstraction, a language that most people find difficult and forbidding. It is precisely that abstraction, of course, that has enabled science to express relations in the physical world in terms of such great general laws as those of gravity and relativity and quantum mechanics. But it is also the reason why science is an "inaccessible language" for most people, a term the later philosopher Charles Frankel used to describe physics but which is, as far as most people are concerned, applicable to the other sciences as well.

And yet when we turn to the realm of personal experience—to the everyday world in which we must decide whether to plan the day by consulting the horoscope in the morning paper, in which we must choose among the Beverly Hills or the Scarsdale or the Meditation diets—we find that experience often fails, that it doesn't always steer us right. Whether you call it intuition or common sense, that distillation of our experience that we use as a guide in evaluating new information and in making choices about our life is, in its own way, an inaccessible language too. It is inaccessible in the sense that we often don't know how to interpret it or how to translate it into a few solid, reliable, general truths on which to base our decisions and our beliefs. The results of this inability are sometimes amusing and sometimes tragic. It exists because we live in a world in which coincidence and statistical fluctuations are just as likely—or even

more likely—to be at the root of much of what happens to us as any causal factor. That makes it extraordinarily difficult to generalize from experience, though the very process of living forces us to do so.

We need to recognize that, in dealing with these kinds of questions, we are dealing with the deep human need to find an explanation for the world and for what happens to us. There is something in all of us that resists the notion that the universe is chaotic and that events are random and beyond our comprehension. The ancient myths, which in virtually every culture explain how the world came to be created and how it works, respond to these universal needs. These myths are attempts to explain not only the manifestly orderly aspects of the cosmos—the regular motion of the sun and the moon and the planets—but also those aspects that are apparently random and chaotic. Earthquakes and volcanos may be no less destructive if you see them as the rumblings of an angry god, but they make a lot more sense. Humankind has always devised stories to explain the inexplicable, to keep at bay the notion that the universe may be not merely hostile but meaningless as well.

If modern science has diminished our capacity to believe these mythic cosmologies in any literal sense, it has in no way diminished our longing for a faith of some kind. This need to find a reason for what happens to us extends to things which may simply have no explanation at all. We all recognize that we can be lucky or unlucky, fortunate or unfortunate. We are less eager to recognize that luck and good fortune are statistical fluctuations. Superstition is the attempt to control events that are really matters of chance, which is why gamblers believe they are more likely to win when they wear their lucky ties or when they bet on their lucky numbers. That we accept anecdotal explanations of chance events, of happenstance, is another manifestation of the stubborn human need to connect events in some meaningful way, even if they aren't connected at all.

In our thinking about liberal education, there has been insufficient recognition of the fact that science and religion and myth attempt to address the same elemental human need, the same unquenchable desire for an organizing principle that can serve as a guide or polestar and help us understand the world and our place in it. The view of science as a destroyer of faith is not merely superficial; it is wrong. Science begins with the assumption—as an act of faith—that the universe is orderly enough to be susceptible to explanation and understanding.

But more than orderliness is required, as the ancient Greek philosophers realized. The universe would be fundamentally incomprehensible were it not fundamentally simple, were it not made up of a few elementary components. And because the Greeks believed that at bottom it must be comprehensible, they postulated the atomic nature of matter. In this century we have finally demonstrated through systematic experiment that the universe is indeed made up of elementary particles, but in a sense which involves modes of description and physical domains entirely outside those accessible to the ancient Greeks. This story, stretching over two millenia, should be understood to mean that more than faith, more than pure reason is involved in science. The tools of science are observation and experiment, but no amount of experiment and observation could produce more than a catalogue were the universe in all its vastness and variety not describable in finite terms. That it has turned out to be so describable, at least thus far, was to Einstein the great miracle, and the most profound of mysteries.

Why then, do we persist in treating science as if it were a separate culture, even as if its values were opposed to those of the humanities, when it is addressing the same universal concerns as those that produced the Bible and the great literature of mankind's ancient myths? Is its language so much more forbidding than Sanskrit or Greek? And how can we provide our liberal arts students with any understanding of science if they, and their mentors, don't first understand and accept the deep connection between science and the humanities?

I've been struggling to identify and spell out what it is we ought to be doing if we are to provide a liberal education in today's technological world. Let me summarize what I've been saying, which reflects the present level of my understanding about this difficult and complicated subject.

What I've suggested is that the problem we need to address is our inability to distinguish between sense and nonsense when it comes to matters connected with science and technology. Liberal education is a failed idea as long as our students are shut out, or only superficially acquainted with, knowledge of the kinds of questions science can answer and those it cannot. Nor can liberal education be considered a success as long as students are unable to evaluate the evidence of their own experience. Liberal education, in the ideal and in the reality, should establish a common sense or intuitive basis that students can rely on in deciding what—and whom—they will

believe. From this point of view, it seems to me that our goal should not be to teach students the practical side of science—science as a skill. There's nothing wrong with learning the chemistry of cooking or the basics of how an automobile works, but I don't believe that people who have mastered such subjects are any less susceptible to the claims of astrologers or clairvoyants—or scientists, for that matter. Watered-down versions of regular science courses, such as Physics for Poets or Astronomy for Lovers, are as offensive and insulting as would be Poetry for Physicists or Shakespeare for Chemists. And as wide of the mark.

Instead, what I am suggesting is an approach that is at once more modest and more ambitious than that. I don't intend to define a list of courses, but I do believe that any course of study worked out should incorporate the following characteristics. First, it should be designed to help students understand the nature of physical laws, what they are and what they are not; what they can tell us about the physical world and what they cannot; how they are arrived at; and in what sense they are true. Second, it should provide some grounding in the laws of probability and chance, and thus some understanding that in a world as complex as ours both statistical fluctuations and the accidental coincidence of unrelated events happen all the time. Many events are unexplainable, are simply happenstance, much as we would like to believe otherwise. Third, it should convey the important idea that science is not a collection of isolated facts but a highly unified and consistent view of the world. In many ways it can be described as a web—a conceptual, empirical, theoretical, and historical web, nearly but not quite seamless.

We need to give our students some sense of why we believe the world and everything in it is made up of small particles; why we believe in our modern grand theories, such as relativity, when past grand theories have been proven wrong. Newton's theory, after all, has been superseded by Einstein's; the chemists' proof that matter is immutable, itself a correction of the earlier views of the alchemists, has been superseded by the discovery through nuclear chemistry that it is indeed possible to transmute base metals into gold. Pasteur's proof that spontaneous generation was impossible has been replaced by the views of modern biologists, who are convinced that life itself most likely began spontaneously.

We also need to make clear, to approach this from a complementary point of view, why it is that scientists can make with

reasonable confidence assertions that seem to ignore anecdotal evidence that so many others find persuasive. Our students should be able to understand why physicists accept relativity and not precognition, or why they accept the likelihood of extraterrestrial intelligence and the overwhelming unlikelihood of UFOs, why they regard attempts to describe the first three minutes of the universe as sense and not nonsense. The reason, of course, is that science has a foundation of large general laws that link together various observations about the physical world and which provide a framework within which various potentialities, facts, and theories can be evaluated. And when a generalization that has long been believed proves no longer true, it is usually because the physical domain in which that generalization was valid has turned out to be a limited one, more limited than actually exists in nature. The discovery of radioactivity demanded radical revisions in our view of nature because it arose entirely beyond the boundaries of what was then known. It should be possible—I have no doubt that it is possible—to convey to students both the power and the limits of general scientific laws and why we can, in the light of both, draw reliable conclusions from those laws.

It should be clear from all of this that what I am talking about does not have to do with the teaching of skills but with education in a broader sense. Not that skills aren't useful and desirable. The more mathematics you know, the more physics you can understand; the more physics, the more chemistry. But I am not so ambitious as to think that it is going to be possible to give all students a thorough grounding in mathematics and the sciences in the course of a liberal education. Obviously, we can't expect liberal arts students to master mathematics and physics and the other sciences to the degree necessary to permit them to understand and use the laws of nature in the same way that physicists and chemists do. For students who don't have those skills, however—that is, for liberal arts students—the sort of scheme I have outlined should nonetheless be an attainable goal. And of course the more science and mathematics they have studied during their school years, the more readily that goal can be reached.

In thinking about the question of how to educate students for life in a technological society, we need to be armed with the recognition that it is no easy task; on the contrary, as our past failures continue to remind us, it is enormously difficult to do. What can be accomplished will depend on the kind and number of people who

get involved, on the resources available, and on the kinds of programs that already exist. But I think we are fortunate—and I like to believe that the reason is the general soundness of our educational system rather than happenstance—in having two different sets of institutions within which to address the problem in as serious, thoughtful, and detailed a way as it deserves. Research universities are peopled by faculty who are engaged in enlarging our knowledge and understanding of nature; liberal arts colleges have as faculty members people who are deeply committed to the idea and the ideal of a liberal education. We need to take advantage of both sets of interests, to experiment with and learn from each. We need to take advantage of those two important resources. I hope that you will include in your deliberations some consideration of the best ways to do so.

I have tried to connect science as an intellectual activity to the same wellsprings that motivate us to study the liberal arts. If the ability to distinguish sense from nonsense is an indispensable aspect of a liberal education—and I have emphasized my own belief that it is—then in a technological society science is an indispensable part of the liberal arts curriculum. The study of science and the study of the liberal arts have for too long been considered separate and separable activities. They are not, and at bottom they never were. It is time to bring them together.

Conference Recommendations

Scientific and technical developments impinge on every aspect of life in the 1980s. From computers and microprocessors to electronic mail, from genetic engineering to new treatments for cancer, from space probes to satellite communications—our lives are molded by scientific and technological advances. Moreover, these advances and their applications are often subject to considerable controversy and political debate.

Twenty-five years ago Sputnik set in motion a national concern for science and technology that led to new courses and programs from the elementary school through college to graduate school. The result was improved specialized studies which, in turn, prepared an increased number of highly competent scientists, engineers, and other specialists who helped restore U.S. leadership in space and other technical fields. But the effort largely neglected the need of other students to deal with science and technology in a rapidly changing world.

Today, besides the need for scientists and engineers, we have at last begun to recognize that without a basic understanding of science and technology, none of us can adequately take our place in society. Physics, chemistry, biology, mathematics, and engineering are as vital to the education of all students as history, art, literature, and other humanities.

A report issued by the National Academy of Sciences in May 1982, entitled *Science for the Non-Specialist: The College Years*, states the current problem well. It points out that most colleges and universities now require for entrance only two years of high school science and little mathematics beyond high school algebra. To graduate from college, most students need take no more than nine credit hours of science or about seven percent of their total undergraduate program of studies. Many of the courses used to satisfy these requirements are of dubious value. In far too many institutions, students are not required to take any science or mathematics.

The conference often used the terms science and technology

as shorthand to mean the necessary work required in the several biological and physical sciences, mathematics, computer science, the history and philosophy of science, engineering, and the new subjects in technology frequently joined with other disciplines in science and society programs. Rather than focus on the subjects of individual disciplines, the conference chose to give most of its attention to the concepts of science and technology as separate but interdependent activities. Science has as its overriding purpose the generation of tested *knowledge* whether or not that knowledge has any immediately discernable practical application. Technology, with a history spanning thousands of years, has action as its ultimate purpose. It is concerned with applications of devices and processes in specific social settings. While the two are different, science and technology are strongly related; it is their *combination* that so powerfully shapes the contemporary world.

As a framework for the recommendations which follow, conferees discussed purposes and goals for the required new emphasis on science and technology. (The conference is indebted to Anna Harrison, professor emeritus of chemistry, Mt. Holyoke College and president of AAAS, who provided a draft statement of goals which reflected the sense of the conference.) The conference believes this new emphasis is required:

- To develop an understanding of the nature of scientific knowledge and of the process of investigation from which the character of scientific knowledge is derived;
- To develop an understanding of the productivity of technology and the nature of the process of technological innovation from which this productivity is derived;
- To explore the impact of scientific knowledge on the manner in which we perceive ourselves, our relations with others, and everything that surrounds us;
- To explore the impact of technology and the products of technology on the quality of life and the environment;
- To develop the interest, competence, confidence, and will to continue to follow scientific and technological developments in areas related to societal concerns;
- To develop the will and confidence to endeavor to participate critically in the formation of decisions in societal matters involving science and technology;
- To develop the confidence to acquire sufficient competence

in specific areas of technology, as needed in one's life and work;

- To develop an understanding of probability and statistics and the place of both in the analysis of societal problems; and
- To develop familiarity with the role of computers in addressing the problems of the next half century.

All of these goals are, of course, equally valid for those who become professionals in science or engineering. They are, however, primarily goals for civic and professional life that must be pursued during a limited period of exposure in the college years. Those who become professionals have a much longer time span in which to acquire competencies in these areas.

The Recommendations

To accomplish these desired goals, conferees made several sets of recommendations for the consideration of all those responsible for education in science and technology in American colleges and universities. Three areas of concern to the conference so affected all of the recommendations and require such immediate action that they are presented here separately.

First, the conference participants believe the seriousness of the situation requires national leadership to restore science to its proper place in the college curriculum. The conference recommends that this leadership should come from an established and on-going organization—such as the American Association for the Advancement of Science—whose goals, program, membership, and reputation will ensure a continuing involvement.

Second, it was the overwhelming consensus that a renewed emphasis on teaching in the sciences and technology is essential, and that senior faculty who are acknowledged leaders must be induced to do more teaching of students who are not majoring in those disciplines.

Third, conferees recognized that making the necessary improvements in the present situation will not be easy. Therefore, they recommend that each college and uni-

versity make a long-term commitment to allocating the necessary faculty time, equipment, funds, and other resources needed to improve science education for non-majors.

The specific recommendations from the conference are grouped around four paramount issues: 1) leadership; 2) institutional commitment and support; 3) standards, both for admission to and graduation from college; and 4) improvement of science courses and introduction of technology courses for non-majors.

The Need for Leadership

If science and technology are to be restored to their proper role in a complete college education, leadership is needed at several levels. Changes will not come about unless individuals, academic departments, and concerned local and national organizations are willing to work for them.

At the National Level

A highly respected national organization will need to undertake the responsibility for acting as the lead agency. This responsibility will not be best served by a new group created solely for this purpose, but rather by an existing organization with the goals, structure, and membership capable of exerting leadership.

- The Wingspread Conference recommends that the American Association for the Advancement of Science (AAAS) take the lead in the national effort to raise the level of education in science and technology for all college students.

AAAS is the largest and oldest general science organization outside of government in the United States. It has over 140,000 members from all scientific disciplines and nearly 300 affiliated societies and academies of science from around the country. Moreover, it has begun an active program to improve science education in elementary and secondary education as well as maintaining its general interest in science education that is aimed at all Americans, not just the science community.

As a national lead agency, AAAS would perform several functions. These include acting as a national clearinghouse for infor-

mation on science education, enrollment, model science programs and courses, and names of organizations and individuals involved in the effort.

Of particular importance, AAAS can and should help mold public awareness of the problem and foster a national debate on the role of science and technology in a liberal education. The debate should extend beyond the scientific and academic communities to the nation at large. Means to open such discussion include commissioning position papers, sponsoring conferences and symposia, identifying science faculty who will work with their colleagues in improving science and technology education for non-science majors, and placing articles on the problem and possible solutions in newspapers, magazines, and journals.

Through regional and state chapters of its affiliated societies, AAAS can expand the momentum built up at the national level into the local arena. The overall goals will not be achieved without significant contributions at the regional and state levels. Building public awareness and a base of political support means reaching decision-makers and other influential persons and institutions within the states, and this can occur more effectively through participation by regional and state organizations. Efforts must be made to involve the state higher education boards and commissions, state associations of private colleges, regional educational groups, and others who are active in specific localities.

In assuming this national leadership, AAAS should not have to act alone. Other scientific, mathematical, and engineering organizations that should offer assistance and advice include the National Academy of Sciences (NAS); scientific societies like the American Chemical Society (ACS) and the Mathematical Association of America (MAA); engineering societies such as the American Society for Engineering Education (ASEE); the Association for Computing Machinery (ACM); and associations of educators and institutions of higher learning like the Association of American Colleges.

On the Campuses

- The Wingspread Conference recommends that science, mathematics, and technology faculties initiate the process of course and program development needed to raise the level of science instruction for all students.

Leaders in the sciences, of course, should actively seek to in-

volve faculty members from other disciplines, both to gain broad acceptance for the revitalized emphasis on science, and to encourage their colleagues in other disciplines to incorporate appropriate aspects of science and technology into their own teaching.

- The Wingspread Conference recommends that the senior faculty in the sciences and technology take the lead in conceptualizing and designing science programs and courses and in teaching them to non-science undergraduates.

The conference believes that leadership by senior faculty members is of particular importance. Not only do they have the experience and respect needed to speak persuasively to other faculty members, departments, and administrators, but their research and publications have already gained them tenure, thus providing them more time to give attention to science education.

- The Wingspread Conference recommends that academic deans and other administrators acknowledge the importance of science and technology education for all students and provide the necessary campus leadership for program adjustments.

With the support of their faculties, academic administrators can bring pressure to bear on presidents, chancellors, and boards of regents for program improvements and for the resources necessary to implement them. Their role could well be the key to gaining the necessary support.

Institutional Commitment and Support

- The Wingspread Conference recommends that colleges and universities place high priority on providing the resources necessary to establish strong programs that incorporate science, mathematics, and technology for all undergraduates.

In some cases, a reallocation of resources within a college's or university's existing budget—without significantly damaging other academic programs or creating unnecessary opposition to strengthening science education—may be sufficient to begin the process. More likely, new funds will be needed to hire new teachers, buy

more equipment, and support demonstrations and field studies. In an era of increased costs and tight budgets, such funds will be difficult to find. Individual institutions might choose to earmark a small portion of the funds that support research in science or technology—perhaps two percent of the indirect cost recoveries return to the administration— for curriculum development that emphasizes science and technology for non-science majors. The research enterprise cannot survive, after all, without the support of well-informed civic leadership and the general citizenry.

Standards for Admission and Graduation

With the movement to expanded access to higher education over the last twenty years, many colleges and universities have abandoned or greatly weakened science and mathematics requirements for most students; few entering freshmen to have taken more than two years of high school science or mathematics. Moreover, too few students graduate from college with sufficient understanding of the basic concepts and processes of science, mathematics, and engineering. Indeed, many colleges and universities require no more than one year-long course in science—if that—to graduate. Colleges and universities need to reexamine the role of science, mathematics, and engineering in a liberal education; what learning in science and technology is essential for persons who can function effectively as professionals, businessmen, and citizens in our increasingly technological society? Understanding these needs should lead to new standards in the sciences and related fields, both for admission and graduation.

- The Wingspread Conference recommends that colleges and universities spell out clearly what science, mathematics, and related courses students are expected to take before they enter college.

By requiring students to take more science and mathematics in high school, college and university students will be better prepared for work in science, mathematics, and related courses.

- The Wingspread Conference recommends that, as a minimum, ten percent of all students' programs should be devoted to learning in the sciences and technology and that all students should be required to take work in mathematics,

beginning at the level indicated by their high school courses and appropriate tests.

For advanced students, perhaps courses in applied mathematics, statistics, or computer science could be substituted for basic courses. But all students should take some work in mathematics or quantitative reasoning in their college program.

Revitalization of Courses and Improvement in Teaching

If the goals envisioned by the conference are to be achieved, curricula will have to be changed, the contents of courses revised, and the process of teaching revitalized. Too often current courses for non-science majors are simplified introductions to the major field; they fail to provide general knowledge about science and technology as enterprises or to educate for citizenship required of both the future scientist and the non-scientist.

- The Wingspread Conference recommends that institutions redesign science, technology, and related courses to give all students a greater ability to understand scientific and technological concepts and processes, and to apply them in analyzing and evaluating problems involving scientific or technological matters.

Individual courses should seek to improve the understanding of scientific investigation and technological innovation. They should attempt to show where and how linkages can be made between cause and effect so that appropriate conclusions can be drawn. The courses should also emphasize the pervasive presence of uncertainty and risk when analyzing private and public policy issues involving science and technology.

Students should learn about the processes of scientific investigation and the nature of scientific knowledge derived from these investigations, including at least one course each in mathematics and in a physical or biological science with laboratory. Students should also be introduced, through credit or non-credit courses, to the structure of computer languages, concepts of computational analysis, and other aspects of computing as a scientific and technological tool. Students should be exposed to engineering principles, processes, and practices. Good courses will demonstrate the nature and complexity of engineering problems, and the concepts and characteristics

of modern technology. A third level should introduce questions of personal and social values raised by science and technology in a historical and cultural context. Philosophical, religious, social, aesthetic, and economic issues introduced by scientific discoveries and technological innovation need consideration from a variety of perspectives.

Since many colleges do not have engineering schools or programs, faculty in those institutions will have to develop the engineering and technology concepts to be presented. Colleges might work out cooperative arrangements with nearby engineering programs and share or exchange faculty. Faculty, including those in science and engineering, might be given time to observe or work in industry as a means of gaining up-to-date experience with technology. Specialists from industry might help teach courses that require special knowledge or aspects of engineering.

Problems in establishing coherent requirements in science and technology will undoubtedly emerge as students move from one kind of institution to another. Large numbers transfer into a four-year college or university from community colleges; fifty-three percent of all college students today begin at junior or community colleges. Additionally, adults take work in a variety of institutions at different speeds and often over long periods of time. All of these factors affect the ability of any one institution to assume a complete education for its graduates.

- The Wingspread Conference recommends that science, technology, and related courses be made more interesting by emphasizing first-hand learning about scientific phenomena through vivid demonstrations, laboratory experiments, and field studies; such approaches can be used to give meaning to the processes, concepts, and philosophy of science taught in the classroom.

Raising science requirements and redesigning curricula for undergraduates alone will not remove the stigma of dull, technical, and difficult subjects that many non-science majors often attach to science and technology courses. Such students are less likely to learn the concepts and be able to use them later in life. Some of the new tools for improving instructional design and communciating science address these concerns. Emphasis might be placed on the microcomputer and on videodiscs which offer the possibility for "hands-on"

simulation in a non-laboratory environment.

To help faculty improve science and technology teaching, resource centers might be established on campus to act as storehouses of information on methods useful in teaching science and technology to non-majors. Additionally, regional networks might be established among groups of colleges to disseminate information and conduct workshops and symposia on course design and teaching methods. Thus, small colleges could have access to the experience and greater resources available in larger colleges and universities.

- The Wingspread Conference recommends that colleges and universities renew recognition for the importance of teaching science and technology, particularly to non-majors, and reward faculty members who make outstanding contributions to teaching.

Professors who put their greatest emphasis on teaching students—rather than research and publication—frequently feel looked down upon by their peers; they may experience difficulty attaining promotions and other rewards. To divide faculties into those who instruct and those who investigate would not be desirable, especially as research invigorates instruction. Younger, as yet untenured faculty will require some measure of relief as they work to build a research record, but this should not exclude their participation in the new instruction. However, the main burden for these new initiatives will fall upon the established faculty, and a system of recognition, reward, and support is desirable.

To improve the rewards for special teaching, grants could be awarded to interested faculty members to develop new programs and courses and an emphasis on teaching could be considered in the award of salary increases and honored chairs. Interdisciplinary programs of teaching science, mathematics, and technology to non-science undergraduates might be an effective structural device with their own chairs and faculty evaluation systems.

At the national level, working with AAAS, science societies should be encouraged to consider excellent achievement in teaching among the factors used to determine recognition of individual scientists, mathematicians, and engineers. In particular, the National Academy of Sciences and the affiliated National Academy of Engineering and Institute of Medicine might include evidence of outstanding teaching in the review of nominations for membership.

AAAS itself might inaugurate a special program to honor scientists who develop new courses or programs in science education.

- The Wingspread Conference recommends that graduate departments in science, mathematics, engineering, and technology help prepare graduate students to be teachers as well as scientists.

Graduate programs have assumed that the more one knows about a particular discipline, the better prepared one is to teach it. New approaches may be needed to teach science and technology to non-science majors, and faculty members may need assistance in teaching new courses to new students. As a result, graduate students might spend more time teaching classes, under the supervision of faculty members, along with time spent doing research. There may be potential benefit in cooperation between science, mathematics, and engineering departments and colleges of education within each college or university. Science departments can help colleges of education prepare more and better elementary and high school science and mathematics teachers; they have an interest in attracting bright students to teaching in order to ensure that entering college students are adequately prepared for college science and mathematics. Students who receive their training in the new science courses and programs and enter teaching are vital, in turn, for preparing students for college-level science and mathematics.

As a society, we need to reorder and refocus our science and technology education as we prepare our young people to live in peaceful and productive ways in rapidly changing, increasingly smaller global villages. Strategies for cooperative problem-solving may mean our very survival. Undergraduate curricula to help students comprehend basic scientific and technological concepts are a pressing need for all who will function in this and the next century.

The Wingspread Conference on Science and Technology Education for Civic and Professional Life: The Undergraduate Years

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